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PMAD FOR THE NEXT GENERATION SPACECRAFT

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ABSTRACT

The next generation spacecraft is reducing the power, mass and volume envelope for the power system. The Power Management and Distribution (PMAD) function has traditionally been the hugest consumer of power system allocations (excluding the source.) On Cassini, PMAD was 75% of the allocated power, volume and mass for the power conditioning equipment. The next generation spacecraft has defined the need for power system miniaturization and multi-mission adaptability.

The PMAD functional block provides power conversion and the load switching interface between the user and the power system. Power conversion will provide the user specified voltages and internal PMAD house keeping power. Every load is connected via a power switch which protects the system from load faults and provides telemetry. A command interface is provided to control the switches and access telemetry.

The PMAD miniaturization approach is to reduce the size without losing system flexibility The functions of PMAD can be broken down to repeated functions and system specific functions. The repeated functions are candidate-s for in-accessible packaging techniques such as hybridization and mixed signal ASICs. The system specific functions must utilize packaging techniques which are either accessible or programmable.

The load switching function is repeated for every load on the spacecraft. Cassini used a first generation hybrid power switch (SSPS). The SSPS is designed specifically for the Cassini system. The next generation power switch will be a simpler version with the capability to switch different voltages on either the high or low side. The new topology permits different switch configurations to accommodate specific load requirements. The switch will still provide the telemetry and fault protection required for each load. The added flexibility will increase the functional adaptability of the PMAD functional block to different load classifications.

Power conversion contains both repeated functions and system specific functions. The pulse width modulation (PWM) and synchronous rectification arc repeatable among different power converters. The power transformer, input/output filters and control feedback loop are accessible outside of the hybrid. The hybrid can be used in different topologies to optimize performance for different system requirements. The hybrid power converter combines high density packaging with system design flexibility without sacrificing efficiency.

The command interface is a mission specific function. Recent developments in field programmable gate arrays (FPGAs) have provided a means for miniaturizing the command interface without sacrificing the system flexibility. The FPGA is important to maintaining multi-mission capability without invoking a command interface standard.

The next generation PMAD is answering the challenges from the "faster-better-cheaper" mission profiles. The high density packaging combined with design flexibility provides a fictional PMAD building block for the power system. The next generation PMAD provides system adaptability without sacrificing power, mass and volume.

THE NEXT GENERATION SPACECRAFT

The challenge of the next generation spacecraft is to shrink the power, mass and volume envelop while maintaining a certain amount of system level flexibility for a multi-mission capability. The next generation spacecraft will be used for multiple missions. Each mission will have different requirements

The next generation spacecraft requires a reduction in power electronics mass by 650A, volume by 80°/0, and parts count by

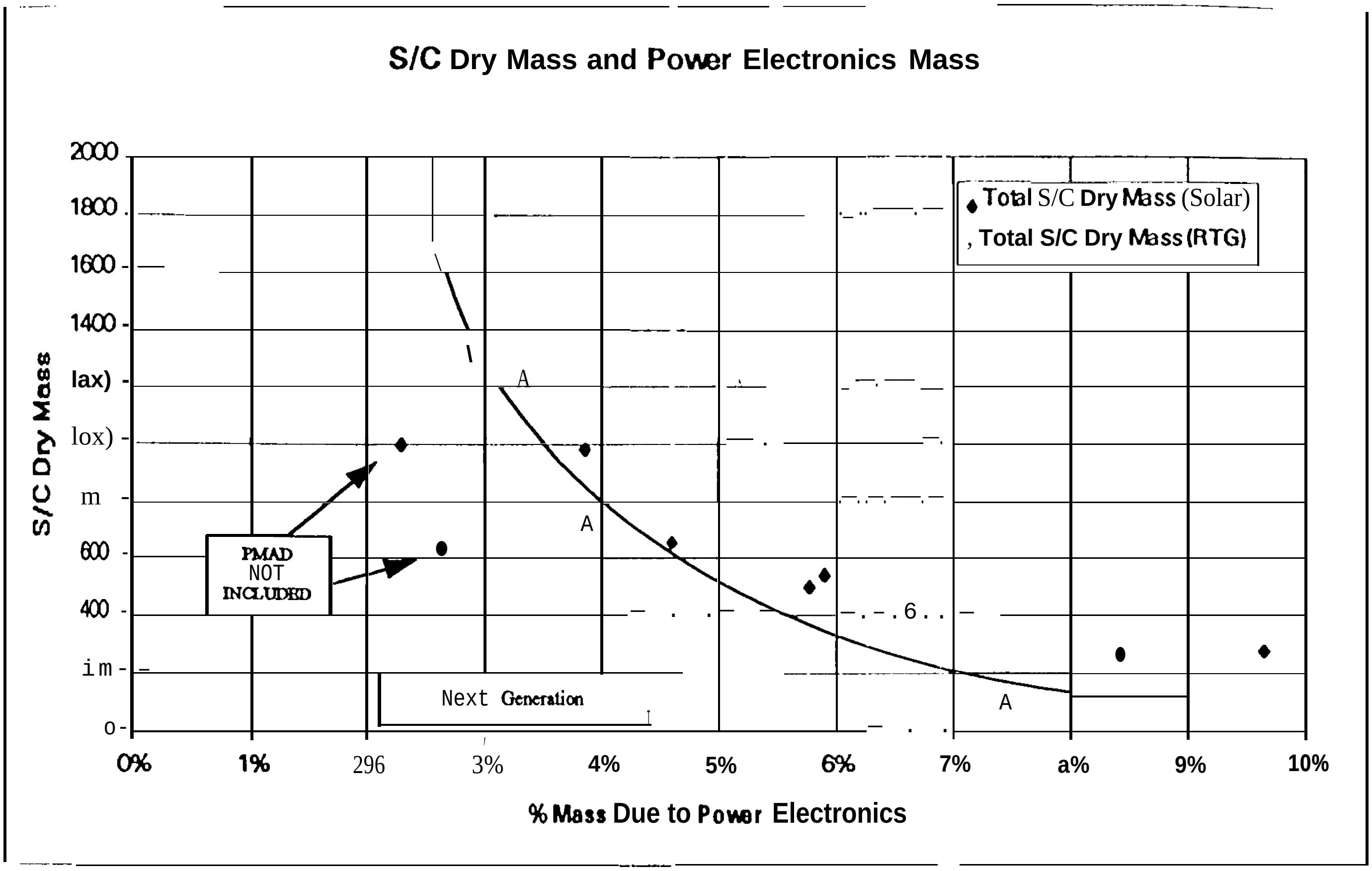

FIGURE 1 - POWER SYSTEM MASS TREND

90??. The trend for JPL spacecraft can be seen in Figure 1. To gain the maximum volumetric and mass efficiency the power electronics will be packaged in the same multi-chip-module (MCM) stack as other avionic equipment. Additionally, physical interfaces must be standardized within the concept of the MCM stack.

Standardization of power interfaces on a spacecraft or even over several missions has always been allusive. Though requirements are placed on the loads, each and every load ends up with specific requirements which are unique. This has been one reason for the increased number of power converters designed internal to the loads. The concept of centralizing that function within the power system while maintaining the flexibility to deal with unique load requirements is very attractive because it reduces the amount of hardware on the spacecraft. This is one way to help reduce the mass, volume, and parts count required for the power electronics on the next generation spacecraft.

Unfortunately, analog technologies such ss power electronics have not seen such advances in high density packaging as in the digital technologies. High density analog packaging techniques available today, such ss hybrids and mixed signal application specific integrated circuits (ASIC), have high non-recurring engineering (NRE) costs. In order to meet the cost constraints imposed by today's economical environment, these NRE costs must be spread over a number of missions thus imposing a de-sign architecture which can be repeated from mission to mission.

The power system functions must be divided into those which are repeated throughout the subsystem snd those which are load or mission specific. The repeated functions can be placed in high density packaging in which the NRE costs are an acceptable trade to reduce the mass and volume of the power system. The power system is developed around these functions.

The load specific functions must be packaged in a way which is accessible within each MCM slice. These firnctions will provide the interface for the repeated functions.

NEXT GENERATION POWER SYSTEM

The next generation power system is a modular design which utilizes high density packaging. The basic architecture can be seen in Figure 2. This power system is expandable and flexible to satisfy the varied future mission requirements.

The power system is divided into four fictional areas. The Source/Energy storage provides the raw power to Power Control.

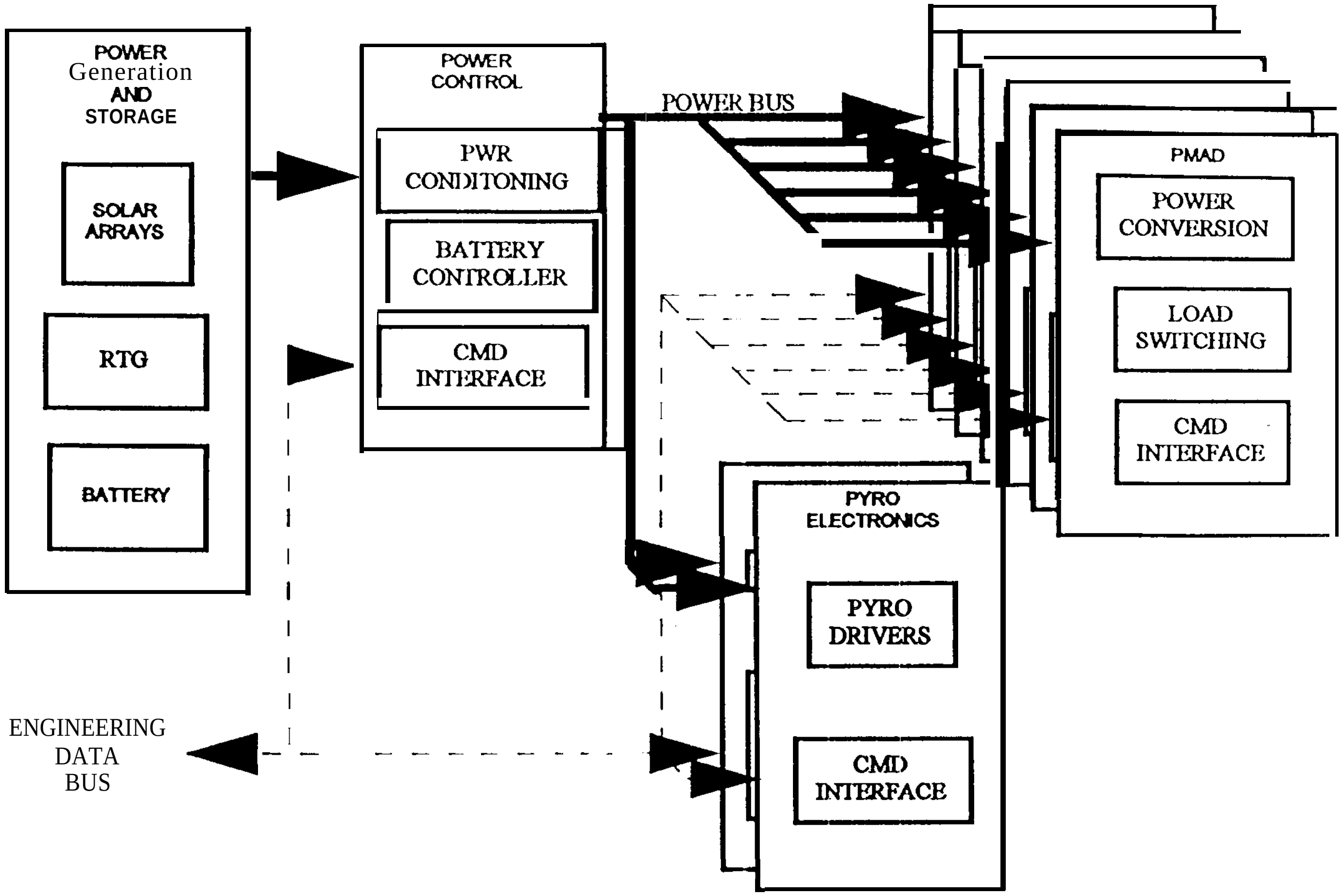

FIGURE 2- POWER SYSTEM BLOCK DIAGRAM

Power Control defines the power bus which is distributed to the PMAD and Pyro Electronics modules. The engineering data bus is distributed to each module which requires commands and telemetry.

SOURCE/ENERGY STORAGE

The source and energy storage requirements are different for each mission. These requirements directly impact the design of Power Control.

The power source of the next generation spacecraft is primarily Solar Arrays though some missions may only be achievable with a radioisotope power source. The size and number of the solar arrays Will vary from mission to mission. Deep space missions have different requirements than near Earth missions due to the large variations in Solar Intensities and temperature ranges. Some missions may require peak power tracking of the solar arrays in order maximize the power output. others may only require a direct energy transfer system.

Many systems will require energy storage such as a battery to provide energy during times when the Solar Array power is not sufficient. A battery system will require strict control of the charge/discharge cycle. Power Control will provide. control of the battery. The charge control algorithm also varies with the type of battery and thus the need for flexibility in the charge/discharge control scheme.

Due to the inability of solar arrays to generate sufficient power far from the sun, some deep apace missions will require a radioisotope power source. The-se sources require Power Control to act an optimum operating point to maximize output power.

POWER CONTROL

Power control will provide mission specific functions such as power conditioning and bus regulation. Other functions which exist on all missions are power bus fault protection and cornmrmd interface and telemetry.

Different sources require different power conditioning in power control. Most near Earth missions will have more power to handle than the deep space missions. Missions further from the Earth must be able to handle the extremes of power generated by the solar array as the sun distance changes. The power conditioning function of power control must optimize the source capability though the mission.

Power control provides the power bus fault protection. This function will vary from mission to mission but there are some fundamental fault protection features in every power system. These functions such as bus under and over voltage protection will reside in power control.

Power control will interface directly to the engineering data bus on the spacecraft. Coremands and telemetry are provided through this interface. An example of Commands required would be charge control settings for the battery.

PYRO ELECTRONICS

The power system traditionally provides the pyrotechnic commanding function on the spacecraft. The command interface is direct link to the engineering data bus. Pym enable and event commands as well as telemetry. The command and telemetry interface for the Pyro Electronics can be the same interface used for the other power system functions.

The Pyro Driver interface design is determined by the technology of the squibs and actuators used on the spacecraft. It is envisioned that the switching technology from the PMAD function can be utilized here to actuate the pyro devices. Design of this function will be dependent on pyro squib development.

PMAD

The PMAD function is to provide power conversion, load switching and fault protection. Each PMAD module is designed the same with a minimal set of components accessible to allow tailoring of the module to the loads. The number of PMAD modules depends on the number of loads and the total power of the spacecraft

PMAD contains its own power converter which converts the power bus voltage to the load specified voltage. It has the added capability to provide auxiliary outputs for house keeping power as well as low power loads.

The load switching is accomplished by 16 power distribution switches. The PMAD switch configuration can altered to meet critical load requirements and provide cross-strapping between two modules. Each switch provides a controlled interface with the loads as well as individual load fault protection.

The commanding and telemetry function is accessed directly with the engineering data bus via the command interface.

PMAD FUNCTIONAL DESCRIPTION

The PMAD primary function is to provide the load interface with the main power bus. PMAD is divided into three functional areas: power conversion, load switching and command interface as seen in Figure 3.

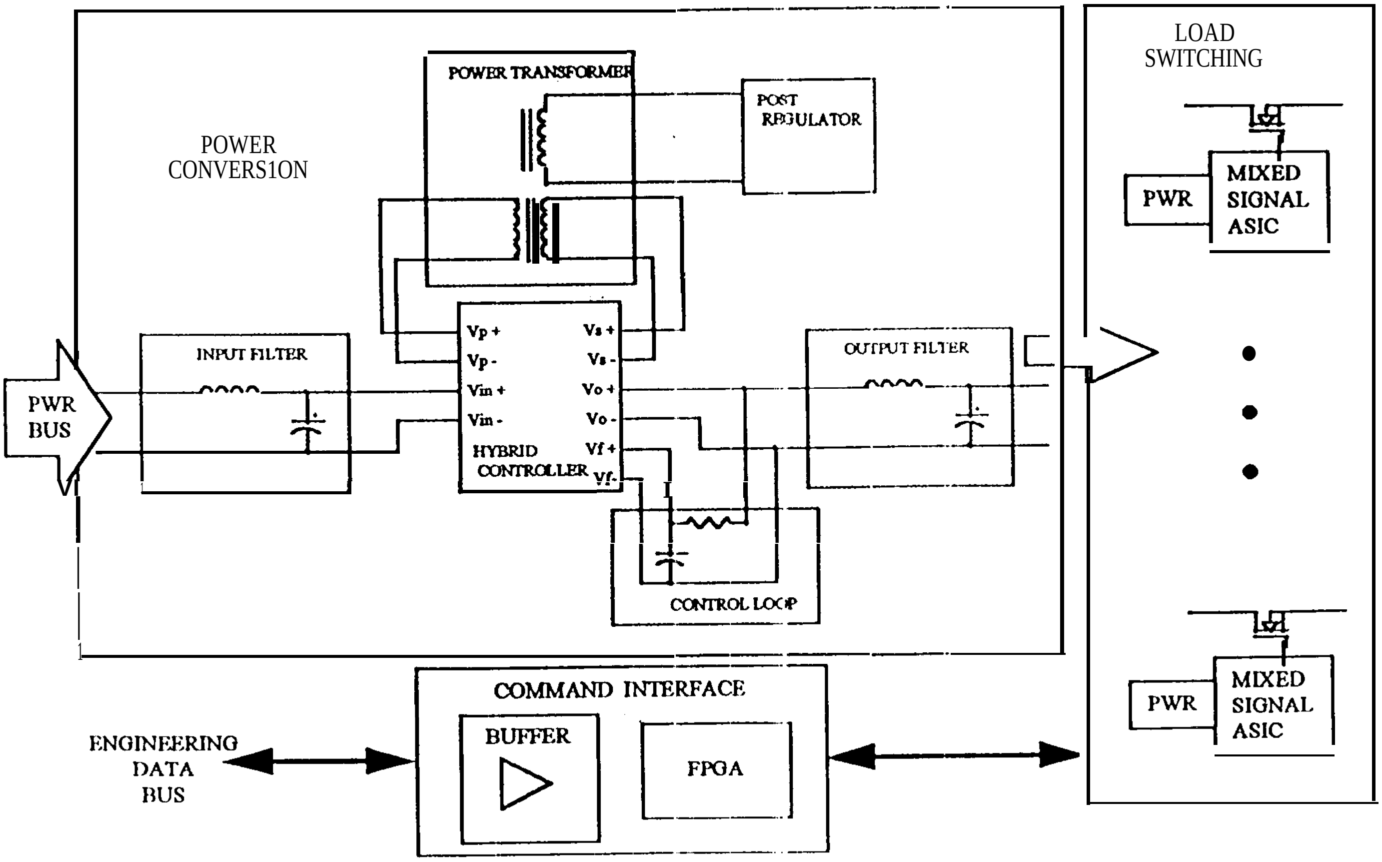

FIGURE 3- PMAD FUNCTIONAL BLOCK DIAGRAM

POWER CONVERSION

Power conversion converts the power bus voltage to the load specified voltages. The power converter consists of a hybrid control circuit with a discrete power transformer, control circuit, input filter and output filter.

The hybrid control circuit contains all of the switching functions of the DC to DC converter. Inside the hybrid is the PWM controller and a synchronous rectifier for the primary output The power converter switching frequency can be synchronized from 50 to 200 KHz.

The primary output of the converter is the specified voltage with the highest load. This output has the advantage of a synchronous rectifier which provides higher efficiency at a high load current (O to 10A up to 50 W). The voltage range of the primary outPut is 2.5 to 12 Vdc. The output regulation is 1%. The overall efficiency of the power converter with a single output is greater than 90% for a output power range of 8 to 30 W.

The primary output is part of the main control loop of the power converter. The control loop response can be modified to meet specific load requirements. The power converter compensation is reduced to a linear control problem similar to opamp stabilization.

Additional voltages are available as auxiliary windings on the main power transformer. The auxiliary outputs will require a post regulator. The house keeping prover of the W module is derived from an auxiliary output. Additional low power loads can be provided by an auxiliary output.

The input filter is designed to meet the power bus impedance and noise requirements. The filter design is determined by requirements imposed by the Power Control to ensure the power bus stability. The input voltage range of the converter is 20 to 50 Vdc.

The output filters are designed to meet the output ripple requirements of the loads. The fitter design will change from module to module on the same spacecraft.

LOAD SWITCHING

The load switching function provides a controlled interface to the load with fault protection, commandability, and telemetry. Load switching is accomplished by 16 power switches. Each switch has a mixed signal ASIC, power mosfet and a transformer. Four independent switches arc hybridized in a single package.

The controlled interface allows multiple loads to be connected to the same power converter. The soft start function enables a load to be turned on without affecting the output voltage provided to the other loads from the same PMAD module.

The current limit function provides control during a load fault. others loads on the same power converter are not affected while PMAD clears a fault. The maximum current is limited to 4A per switch.

The trip level is determined by an I^2T curve. This function forces the switch to trip faster for higher fault currents. The level is determined by an external resistor. The level is configurable to the amount of energy storage available in the system.

Each load is individually commandable. This allows for tighter power management in flight which is necessary for deep space missions with limited power.

Load current telemetry is a available for each switch. The telemetry is provided as a 8 bit digital serial word which can be clocked out by the command interface. The telemetry is a tri-state output which can be bussed together with all the switches in the PMAD module.

Switch power is provided by the PMAD house keeping power. The input voltage range is from 5 to 35 Vdc. The internal power conversion allows the switch to be used in different configurations. The PMAD is able to switch the high or low side of the load.

The power mosfet is an N-channel device with a maximum on resistance of 50 mohm. Switches can be connected in parallel to reduce the voltage drop for high current loads. It also can configured for a series/parallel or bi-directional connection to the load. Additionally, these switches can be configured in various ways to meet critical load requirements or to provide need cross-Strapping between loads.

COMMAND INTERFACE

The command interface is provided by a line driver/receiver and a FPGA. This function is to provide a direct link to the engineering data bus. The line driver/receiver is outsi& the FPOA to be adaptable to the different data bus specifications. some spacecraft may require an isolated interface with the data bus.

The FPGA provides the command and telemetry interface to the switches. The commands from the data bus are decoded and sent to the power switch.

The telemetry is clocked out of the power switch and converted to the appropriate data bus format.

The FPGA also configures the loadshed and power on reset (POR) configurations of the power switches. The FPGA will turn certain switches on following FOR The FPGA will invoke the loadshed command received from the undervoltage fault protection circuitry in power control.

PMAD DESIGN APPROACH

The PMAD design approach is to separate the repeated functions from system specific functions.

All repeated functions are to be either hybridized or covered in a mixed signal ASIC. These parts are to be used for multiple missions. They are the basic building block of the PMAD module.

Load specific functions which use discrete components available by packaging these discrete components in an accessible manner external to the hybrid or mixed signal ASIC. These components can be altered to allow customization of the power interface to the loads.

System level data bus interface requirements are satisfied by the reprogramming of a FPGA. This allows for reconfiguration of the interface from mission to mission.

The PMAD module integrates into a package as onc or more slices in a MCM stack. The exact description and physical interface of this MCM stack will be defined by the next generation spacecraft architecture team. The PMAD architecture described above will allow easy transition of the functions of PMAD into the physical reality of the defined MCM stack.

PMAO CONFIGURATIONS

The flexibility of the PMAD design allows for many different configurations of the modules. The combination of accessible and high density packaging allow for many configurations of the PMAD module. The PMAD is specifically designed to integrate into many different power system topologies. The modules can be located centrally within the physical confines of the power system MCM stack or within the user MCM stack.

SUMMARY

The PMAD module is combining high density packaging techniques such as hybridization, mixed signal ASICs and FPGAs to meet the challenge reducing of the size of power system.

The PMAD design is maintaining level of flexibility which can be customized to special load requirements. The flexibility will ultimately improve the overall efficiency of the power system.

The modularity of the PMAD design enables it to be used on a variety of missions. The number of PMAD modules can be adjusted to fit the requirements of the mission.

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